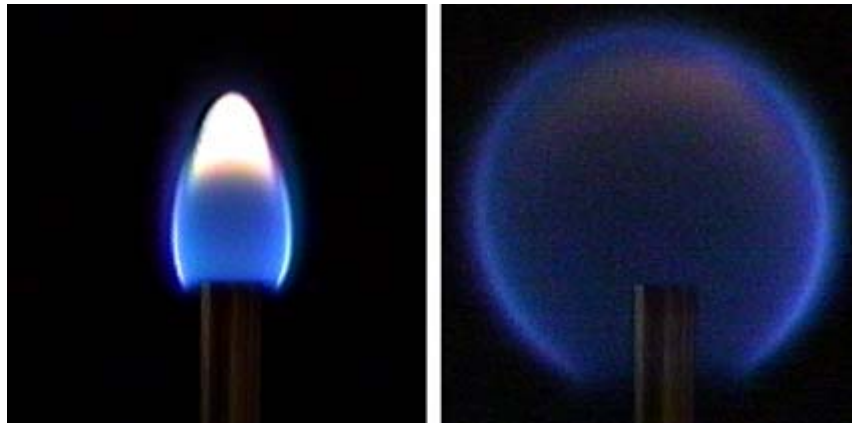


Edge Diffusion Flame Propagation and Stabilization Studied

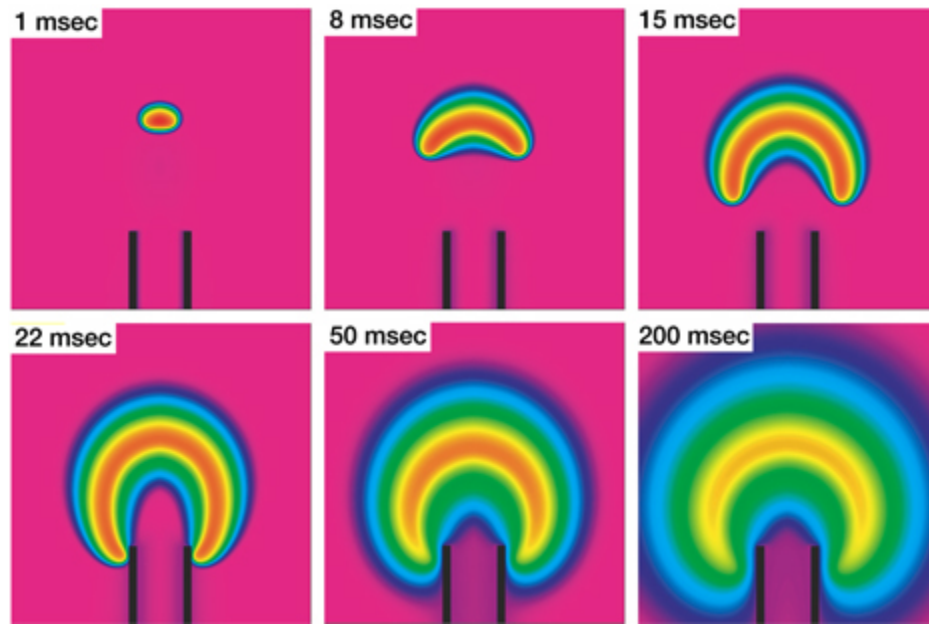
In most practical combustion systems or fires, fuel and air are initially unmixed, thus forming diffusion flames. As a result of flame-surface interactions, the diffusion flame often forms an edge, which may attach to burner walls, spread over condensed fuel surfaces, jump to another location through the fuel-air mixture formed, or extinguish by destabilization (blowoff). Flame holding in combustors is necessary to achieve design performance and safe operation of the system. Fires aboard spacecraft behave differently from those on Earth because of the absence of buoyancy in microgravity. This ongoing in-house flame-stability research at the NASA Glenn Research Center is important in spacecraft fire safety and Earth-bound combustion systems.

Video observations of low-speed fuel jet diffusion flames have been made in normal Earth-gravity (1g) and in microgravity (μ g) at the 2.2-Second Drop Tower at Glenn. The 1g flame was short and narrow, and the flame base was close to the burner rim as a result of buoyancy-induced flow. Intense blue emissions and a yellow-orange color indicated a vigorously burning flame zone and soot formation, respectively. By contrast, the μ g flame was spherical and larger as a result of relatively slow fuel and oxygen molecular diffusion in every direction. The weak burning resulted in lower flame temperatures (thus reducing soot formation) and in a large quenched space near the burner wall.



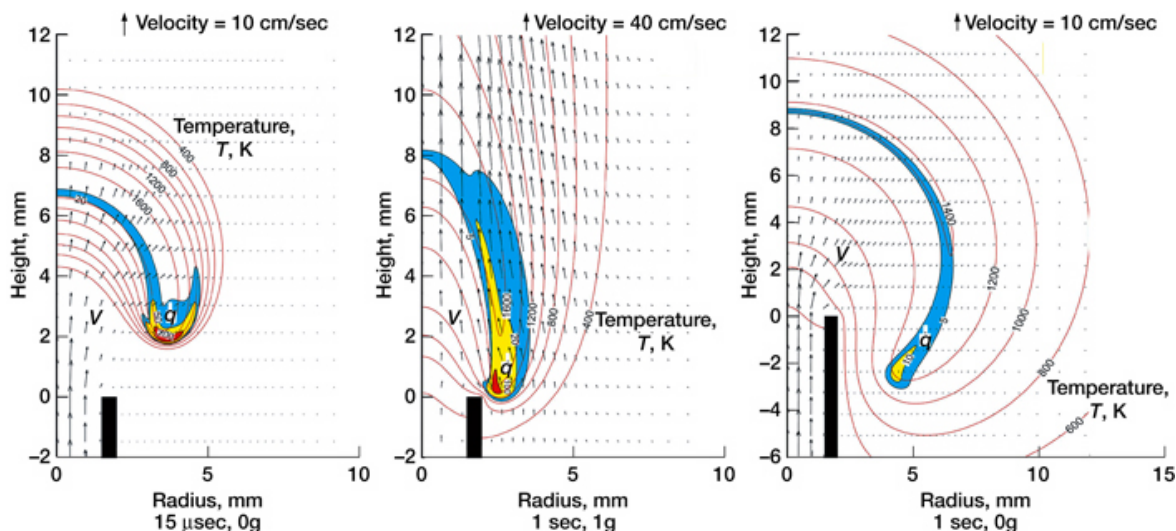
Video images of ethane jet diffusion flames in quiescent air. Burner tube inside diameter, i.d., 2.87 mm; mean fuel jet velocity, 7.5 cm/sec. Left: 1g. Right: μ g.

Direct numerical simulations with a detailed reaction mechanism and radiative heat losses have revealed the flame structure in unsurpassed detail. Unlike previous work, these computations, which used a reaction mechanism including 33 species and 112 elementary steps, enabled genuine prediction of the flame propagation speed. In the simulations, a hydrocarbon fuel (methane, ethane, ethylene, acetylene, or propane) was injected into quasi-quiescent air in 1g or 0g for a short period (0.3 sec) and ignited downstream on the axis. The calculated flame propagation speed was independent of gravity and matched well with the stoichiometric laminar flame speed of each fuel.



Temporal variations (from 1 to 200 msec) in the calculated temperature field of a propagating edge diffusion flame in an ethane jet in quasi-quiescent air in 0g. Burner tube i.d., 3 mm; mean fuel jet velocity, 6.86 cm/sec.

Computations revealed that a peak reactivity spot (i.e., a reaction kernel) was formed in the edge diffusion flame as a result of radical (H atom) back-diffusion into the high-oxygen-concentration region and subsequent chain-branching reactions. The reaction kernel in the propagating flame had characteristics of premixed flames in the direction of propagation. Once the edge diffusion flame attached to the burner rim, its premixed flame nature was lost because the flammable mixing layer became too narrow for propagation and its direction even became perpendicular to the incoming flow. Instead, vigorous reactions at the reaction kernel within an available residence time kept the trailing diffusion flame from blowoff. The 1g flame was stabilized at relatively high velocities because the reaction-kernel reactivity increased by "blowing." A linear correlation was found between the reaction-kernel reactivity and the velocity for each fuel. These new findings replace a conventional view of diffusion flame attachment based on premixed flames and may lead to better fire-extinguishing and flame-holding approaches.



Calculated velocity vectors, v ; temperature isotherms, T ; and heat-release rate contours, q , in joules per cubic centimeter seconds. Burner tube i.d., 3 mm; mean fuel jet velocity, 6.86 cm/sec. Left: Propagating ethane flame in 0g. Center: Stabilized ethane jet diffusion flames in quasi-quiescent air in 1g. Right: Stabilized ethane jet diffusion flames in quasi-quiescent air in 0g.

References

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